study. At a section between Highway 138 and the Lone Pine Canyon, the lines experienced slow foundation movement or shifting at a region were a local bowl or depression exists. The cause was determined to be a high water table fed by surface waters collected in the bowl that allowed the tower foundations to slowly respond to the tension imposed by the lines themselves. The solution was found to be to cover the ground with a concrete mixture so that surface waters would could not seep into the water table at that location. The towers now appear to be stable. On several other occasions, local brush/forest fires have heated the copper conductors to the extent that they partially annealed and sagged. This problem was resolved by retensioning the line in those regions. It is of importance because it indicates the problems that earthquake-induced fires could have on this lifeline system.

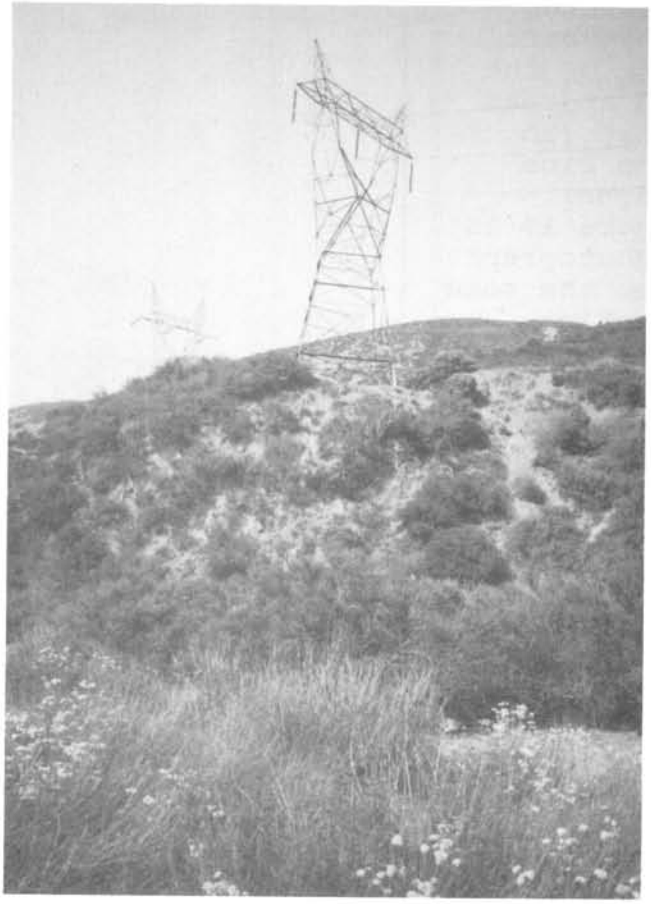

Figure 19 Power Tower At A Ravine Edge In The San Andreas Fault Rift Zone

The LADWP power lines cross the San Andreas fault zone in Lone Pine Canyon very close to where the petroleum products and a 36-inch natural gas transmission line cross the fault trace (see Figures 18 and 19). The expected 12 meter fault displacement causes a damage state 7 to all the lifeline components in this region, with a probability of 100%. The collocation scenario assumes that the resulting petroleum products spill (several miles of those pipelines could drain from the rupture, depending on how many other ruptures are assumed since the petroleum products pipelines run parallel to the fault trace for several miles) causes a 30-day delay in the repair activities while the resulting environmental and fire hazards are evaluated and mitigated. The general congestion in the area and the need to coordinate the use of heavy equipment so that its use will not adversely impact the other lifelines is assumed to add another seven days to the power line repair times. Because of the high probability of damage at this location, the probable restoration time increases by 37 days. This accounts for about 75% of the collocation-induced delays in the restoration of service to the LADWP power lines.

The other significant collocation region for the LADWP power lines is also at Blue Cut. The power lines cross the eastern edge of a landslide zone, and at the toe of the zone at a lower elevation a 36-inch natural gas pipeline is sited next to and in the right-of-way of a rail line. The probability of a slide in this region is 70%, it produces a power line damage state of 5 (heavy damage). The collocation scenario includes a seven day period while the gas line is prepared and tested for leaks, and a increase in damage state to level 6 because of potential natural gas pipeline failure impacts. That scenario increased the repair time from 49 to 66 days and the net impact on the change in restoration time was about 12 days.

There are three 500 kV circuits on SCE's Lugo - Mira Loma system. They were installed in the early 1960s for about 300 kV service and upgraded to 500 kV service in the early 1970s. Line 3 was added in 1983.

Line 1 is to the west, line 2 is in the center, and line 3 is the eastern line. Line 1 is routed south by southwest from the Lugo substation. Lines 2 & 3 leave Lugo station on a single tower system for about 1.5 miles, then they divide into two separate tower systems. The power lines cross the railroad lines a short distance before they cross Highway 138. From there they head generally south until they cross I-15. In this high desert region the only earthquake load comes from shaking characterized by MMI = VII. At that intensity there is no appreciable damage to the towers or the lines, and no collocation impacts were hypothesized.

At the I-15 crossing, lines 1 & 2 cross at the northern boundary of a local liquefaction zone. Because their power towers are located on local hill tops in this region, it is assumed that there are no impacts due to the liquefaction or due to collocation. However, they cross near a concrete culvert that crosses under the highway. At the culvert (see Figure 12) location there is also a metal crib wall (see Figure 13) that provides support to the road bed, the fiber optic cables cross at the same location, there are two railroad bridges in the downstream path from the run off that passes through the culvert, and there is a 36-inch natural gas line which crosses I-15 in the same area. In addition, the crossing is in an area of high water table and of surface water, indicating a potential liquefaction zone. Although the power towers and lines are not expected to experience damage at this location, they will cause some delays in responding to damage on the other lifelines because of the need to work with large cranes and other equipment that could get close enough to the power lines to cause the need for caution to avoid potentials for electrocutions, etc.. Line 3 crosses I-15 further south and is not impacted by the crowded conditions described above.

After crossing I-15, lines 1 & 2 are routed as parallel lines. Where they cross the San Andreas fault they will experience damage state 7 due to the 12 meter displacement expected at the fault trace. The two lines pose a collocation potential that is assumed to increase their repair time by 15 days. This increases their probable restoration time by 15 days because of the high probability that the large fault displacement will occur. After this, the lines again separate, with line 1 heading south, and line 2 heading southeast until it joins with line 3 at Blue Cut.

As line 1 heads south it enters a liquefaction zone that is north and abuts against a landslide zone. Within the liquefaction zone it crosses over the two petroleum product pipelines, the fiber optic conduits, and Cajon Blvd. extension. Near the boundary between the liquefaction and landslide zones it crosses over a 36-inch natural gas pipeline that is itself next to and in the right-of-way of a railroad line. The liquefaction zone results in a 50% probability of damage state 7 occurring to the power towers. The collocation scenario is a 20 day delay due to the general congestion in the region, which results in a probable delay in restoration of 4 days. There are no other significant collocation regions for line 1 further south along its route.

After they join together, lines 2 & 3 head in a south by southeast direction. They cross the Cajon Blvd. extension at the northern boundary of a local liquefaction zone and head up the steep slopes to the higher elevations of the San Gabriel Mountains. Just above the Cajon Pass floor as they rise into the mountains they enter a landslide zone. Figure 17 shows that in the past they have experienced slides that have required extensive repair. At the toe of the slide a 36-inch natural gas pipeline is located next to and in the right-of-way of a railroad bed. The landslide causes a damage state 5 (with a probability of 45%). It is assumed that the congestion and the need to shut down the power line when the gas pipeline is to be tested for leaks will add 40 days to the repair of the power towers. This makes their probable restoration time increase by nine days at this location.

The typical collocation damage scenario is that other lifelines have a minor physical impact on power lines because the power lines are above or removed from the zone of influence of the other lifelines. However, when fuel-based lifelines are involved, they can cause important delays in the power line restoration. This is to assure that the power lines do not become a source of ignition for the fuel. Also, when the other lifelines are directly under the power lines, the expected use of temporary support towers may not be acceptable because of the increased risk of electrocution when other large repair equipment is operated near a temporary tower. As was the case for the communication lifelines, ground movement was the principal cause of electrical transmission lifeline damage.

One hundred and four collocations involving the electric power lifelines were analyzed. The overall estimate of the impact of collocation on the electric power lifelines in the Cajon Pass was:

Lifeline	Increase in Probable Time to Restore Service, days	Increase in Probable Time to Restore Service, %
Los Angeles Dept. of Water & Power	49	28
Southern California Edison Co. Line #1	19	10
Southern California Edison Co. Line #2&3	28	13

Fuel Pipeline Lifelines

Figure 20 shows the fuel pipeline lifeline routes in the study area. The location of the photographs presented in this section of the report are also shown on the figure. The lifelines include one 8- and one 16-inch petroleum products pipelines, three 36- and one 16-inch natural gas pipelines, and the associated valves for each line. Modern buried pipelines of the type installed at Cajon Pass are very resistant to shaking damage. Thus, the earthquake conditions of most interest for the pipelines are the conditions where ground movement is expected. However, when they are buried next to or under another

Figure 21 Typical Long Open Span On The 36-Inch Natural Gas Pipeline

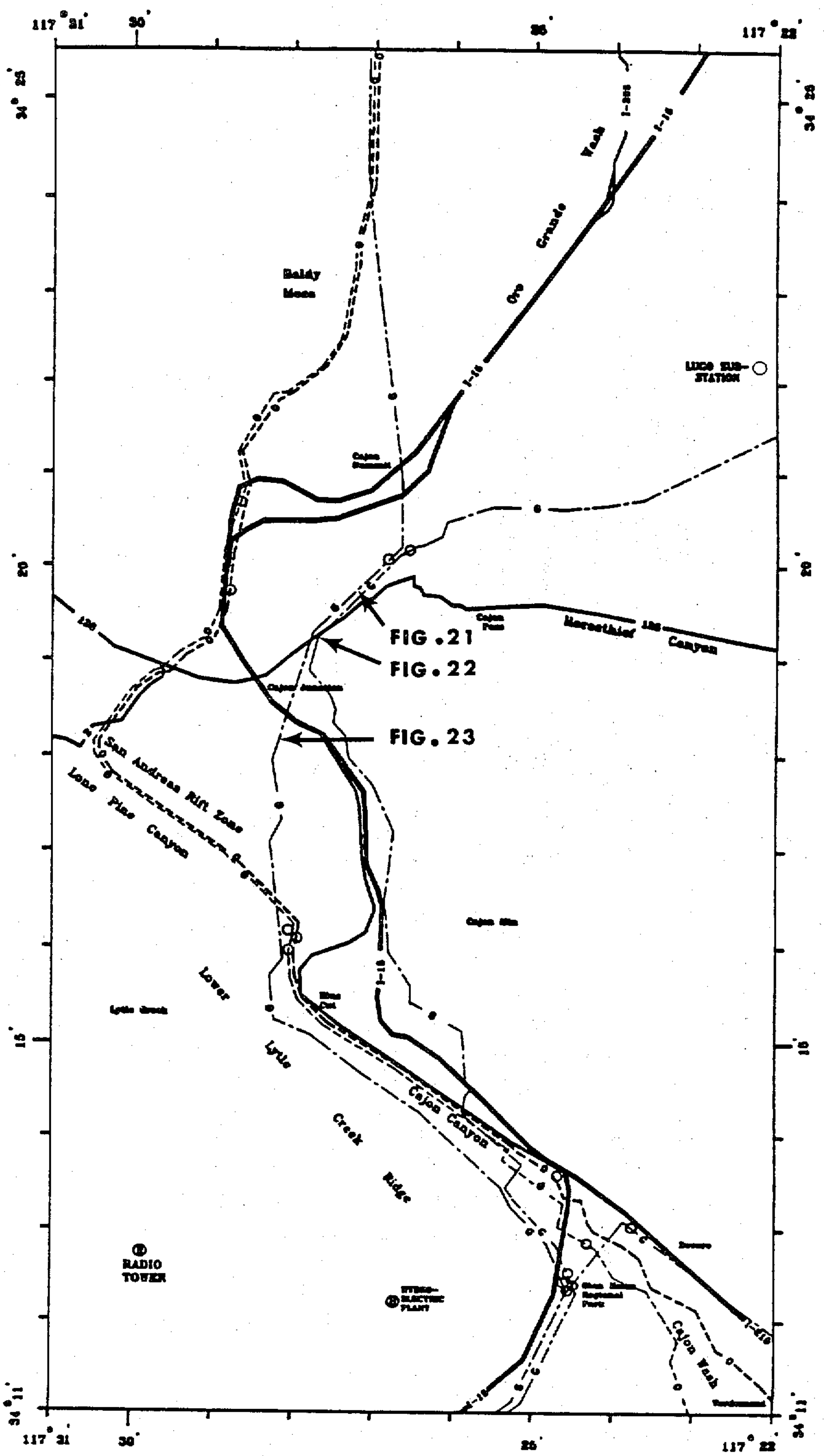

Figure 20, FUEL PIPELINE LIFELINE ROUTES

SCALE

0 1 2 MILES

0 1 2 KILOMETERS

N

EXPLANATION

I-15 INTERSTATE

2 PAVED HIGHWAY

0 0 PETROLEUM PRODUCT PIPELINES

G G NATURAL GAS PIPELINES

VALVES

Larger Scale Figure Located at End of Document lifeline (as they are with the railroads), there is an additional concern that heavy equipment used to remove debris or otherwise restore the railroad lifeline could lead to pipe wall damage of the nearby buried fuel pipeline.

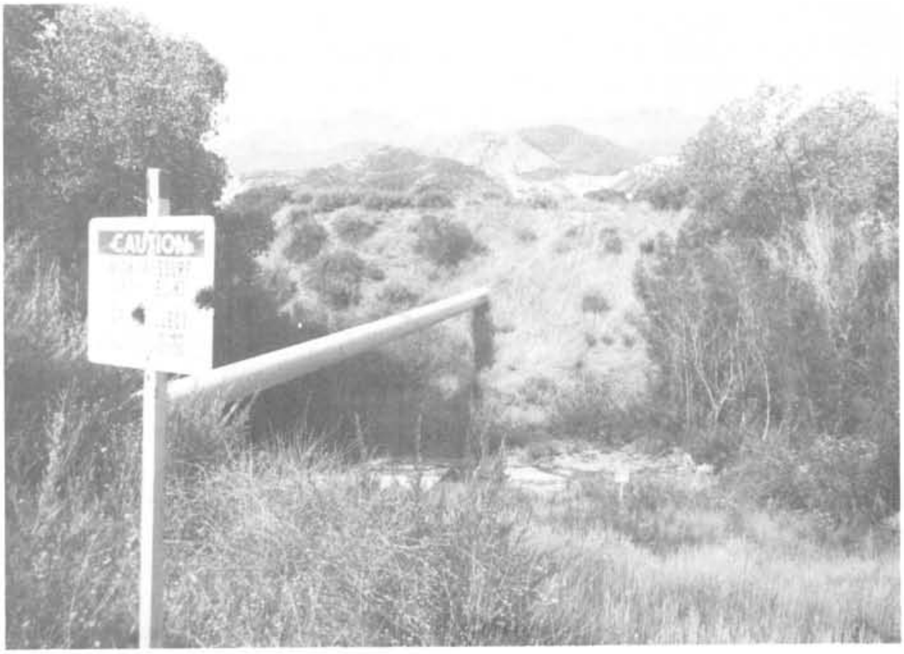

Figure 22 Two Natural Gas Pipelines Near Highway 138, One Buried, One Exposed

Because they are buried, there are no convenient features that can be shown with photographs. However, there are 18 locations along the route of the western most 36-inch natural gas pipeline that are exposed spans which range from 10 to 138 feet in length. Figure 21 shows one of the longer spans across a dry creek bed north of Highway 138 and east of I-15. Figure 22 shows a location about 40 feet from the recently realigned Highway 138. At that location two 36-inch natural gas pipelines are routed parallel to each other. The line on the left is exposed, the one on the right is buried and marked with the surface sign. In general, open spans are estimated to increase the potential shaking damage state by up to 1 level, compared to a buried pipeline damage state condition.

When the pipelines cross under railroads, roadbeds, and sometimes power line rights-of-way, many of the right-of-way owners required the pipeline to be cased inside a larger pipe in the belief that this adds safety and/or it reduces the lifeline interactions if damage on one lifeline should occur (there is a current technical question whether the casing increases or reduces the overall safety of the crossing). Figure 23 shows a location where a 36-inch natural gas transmission line crosses under two different rail beds. One railroad requires the use of the extra casing, the other does not. If the use of a casing increases the safety of the crossing, the close proximity of the railroads means that the extra benefit is lost. If the use of a casing decreases the safety of the crossing, then the railroad expecting extra safety has not achieved it because of the close proximity in this situation.

Two of the most critical collocations involving fuel pipelines were shown in Figures 17 and 18. In Figure 17 the pipeline and the railroads are located directly below a landslide prone area that includes electrical transmission towers. Figure 18 shows that both types of fuel pipelines and high voltage electrical transmission systems all cross the San Andreas fault rift zone at approximately the same location. The results of these conditions are discussed below.

The western most 36-inch natural gas pipeline from valve station 14 (near the Cajon railroad summit east of the I-15/Highway 138 interchange) south to the end of the study area was installed in 1960. The eastern most 36-inch natural gas pipeline was installed in 1966. They operate at a mean operating pressure of 845 psig. The 16-inch distribution supply line branches off of those lines at Valve 15 (south and west of the I-15/I-215 interchange) and provides service to San Bernardino. It operates at a mean operating pressure of 350 psig. The line from the north of the study area (along Baldy Mesa Road) to valve station 14 was installed in 1976. It operates at a mean operating pressure of 936 psig. All of the lines were arc welded and constructed from high grade steel pipe. They deliver 0.6-1.0 billion cubic feet of natural gas per day.

The 8-inch petroleum products pipeline was installed in 1960 and the 14-inch line was installed in 1969. In 1980, several miles of the 8-inch line were abandoned and a new line was routed from the west side of Cajon Creek to join the 14-inch line on the east side. On the east side of Cajon Creek they are routed along the Cajon Blvd. extension. The lines transport a number of refined products, the

Figure 23 Natural Gas Pipeline Crossing Under Railroad Beds

transport a number of refined products, the principal ones being gasoline and jet fuel. They are made of high grade carbon steel. They operate at 1060-1690 psig. The lines pump about 80,000 barrels of fuel per day.

Most of the pipeline highway or railroad bed crossings are cased crossings. However, none of the Southern Pacific crossings are cased, and a few of the I-15 and Highway 138 crossings are uncased. That occurred because the Southern Pacific did not require casing when they authorized the right-of-way crossing, and when I-15 replaced Highway 66 and when Highway 138 was recently realigned (in 1990-1991) they did not follow all of the old routes. At new crossings the pipeline was already installed, and new casings were not required to be retrofit.

In the regions of MMI = VII or less, the shaking damage state for a buried gas or petroleum products transmission line is 1, and no collocation damage is estimated except for unusual conditions to be described below.

Following the pipelines from the center of the northern part of the study area and heading south, the first location for significant damage occurs at the crossing of the San Andreas fault. Here the 12 meter fault displacement is assumed to rupture the lines. The location includes the 36-inch natural gas pipeline and the two petroleum products pipelines (all of which rupture) and the Victorville-Century 287.5 kV lines 1 and 2. The damage scenario includes assuming that an explosion/fire occurs in addition to the discharge of petroleum products. The need to mitigate the impact of the fire and adverse environmental conditions and the delays caused by the general congestion in the area results in an assumed 37 day delay before restoration work can begin. Because of the high probability (100%) of the damage state, the incremental increase in the lifeline restoration time is also 37 days.

At Blue Cut the natural gas pipeline is next to the railroad bed and at the toe of a landslide area. High voltage power lines are located above the gas line in the slide area. A damage state 4 is predicted for the pipeline. The heavy equipment used to clear the railroad bed is assumed to increase the damage state to level 5. This increases the pipeline repair time by 18 days, and the debris clean up adds another 20 day delay. The general congestion adds a 7 day delay. This results in a change in the most probable restoration time of 12 days. Further south the pipeline follows the railroad bed along the west edge of Cajon Creek. About 4 miles further south, the pipeline and railroad are again at the toe of a landslide region. In this case only the 18 day increase in repair time and the 20 day debris removal delay are assumed. This results in an 8 day increase in the probable restoration time for that pipeline, for a total increase in time of 20 days.

Moving from the north to the south, the eastern most natural gas pipeline first experiences a potential collocation damage condition where it crosses I-15 in the region where the fiber optic conduits cross under I-15 in a concrete culvert and the electric power lines cross over the highway. This is a region of potential liquefaction. The damage state is 7 but the probability of damage is only 20% for the pipeline (but 40% for the lifelines that are right in the local creek bed). The pipeline is somewhat removed from the other lifelines, but there are railroad bridges also in the general area. It is assumed that the other lifeline repairs will be based on the requirement that long lengths of the natural gas pipeline will need to be exposed and examined to assure that a leak/explosion potential does not exist while they work on the other lifelines. This leads to a 20 day delay in starting the pipeline repair, resulting in a probable restoration delay of 8 days. About 3.2 miles further south the pipeline passes through another landslide zone near where it crosses I-15, leading to a probable increase in the restoration time of 16 days.

Across Cajon Creek from where the western pipeline was exposed to a potential landslide, the eastern natural gas pipeline crosses perpendicular to the two petroleum product pipelines and the fiber optic cables. This is a potential liquefaction zone that results in a pipeline damage state of 7 with a probability of 20%. There is a 30 day delay while the petroleum product spill is cleaned up and another 7 day delay for general congestion resolution questions. This results in an incremental change in the probable restoration time of 1 day.

Just south of the I-15/I-215 interchange the 16-inch natural gas pipeline crosses a local liquefaction zone. It is collocated with the two petroleum products pipelines, the railroads, and two of the fiber optic cables. The liquefaction results in a damage state 7 with a probability of 40%. The collocation damage scenario assumes a 30 day delay to clean up the petroleum product spills, and another 20 days to account for the congestion and delays experienced because of the repair to the nearby bridges. The net increase in restoration time is 8 days.

The two petroleum products pipelines enter the study area from the south in the Cajon Creek Wash. The 14-inch lines is collocated along the railroad right-of-way, the 8-inch is on the western side of the wash. Just south of the I-15/I-215 interchange, the 14-inch pipeline enters a local liquefaction zone, along with the 16-inch natural gas pipeline, the railroads, and two fiber optic cables. Damage state 7 (40% probability) occurs in this region. There is a 20 day delay due to the general level of congestion, and because the 14-inch pipeline is collocated with the railroad, there will be a requirement to expose and inspect the pipeline before it can be put back into service. This will add another 40 days of delay. This results in a 10 day increase in the probable time to restore service. About 6 miles further north, both pipelines enter another liquefaction region, along with a 36-inch natural gas pipeline and